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LCA FOR AGRICULTURE

Are public payments for organic farming cost-effective? Combining a decision-support model with LCA

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Abstract
Purpose The agricultural sector fulfils several functions such as the production of food energy and landscape conservation. An equilibrium between economic development and environmental protection should be found and research should aid political decision-making. In recent years, great efforts have been made to assess the environmental and economic implications of changes in both environmental and agricultural policies. Life cycle assessment (LCA) has been extended by cost functions and social parameters. The validation of suggestions for political measures can be improved by combining existing environmental and economic models. This approach is applied in this paper in order to compare an increased support for organic farming with specific environmental policy measures, focusing on the resulting impacts and socioeconomic indicators.
Materials and methods The LCA tool Swiss Agricultural Life Cycle Assessment (SALCA) has been linked with the economic optimisation model Swiss Agricultural Sector Forecasting System (SILAS). Since the focus lies on agricultural production, the farm gate represents the system boundary of the LCA. By linking SALCA with SILAS, the classic LCA impact categories have been extended by socioeconomic indicators. A reference scenario representing the assumed development of economic conditions between 2008 and 2015 was varied by a support for organic farming and four specific policy measures (support for ecological compensation areas and a tax on energy, fertiliser and concentrates, respectively). To remain comparable, the changes in total payments were set to the same amount in all scenarios (100 million CHF).
Results and discussion A support for organic farming would have favourable effects on several environmental and socioeconomic indicators, but the differences compared to a combination of the four specific measures are small. However, some of these single measures could reach parts of the targets more efficiently: an energy tax would stimulate the application of available energy-saving measures, and a tax on concentrates would lead to a shift from intensive animal husbandry to crop production, reducing imports of concentrates and emissions of ammonia. Overall, the predicted developments in product and factor prices combined with the assumed reductions of public payments until 2015, as represented by the reference scenario, have the greatest effect on environmental impacts.
Conclusions Theoretically, specific policy measures are more efficient than measures directed towards multiple goals. Especially in the case of agriculture, however, a specific measure not only has an impact on the associated target but affects all agricultural functions. The results of the model combination suggest that a support for organic farming lowers the risk of undesirable side effects on environmental and socioeconomic indicators. Before implementing more specific measures, their impacts on the different functions should be estimated. For this purpose, a combination of decision-support models with LCA may be an appropriate instrument.

Keywords Decision-support model · Environmental policy measures · LCA · Organic farming · Political advisory

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1 Introduction

Previous life cycle assessment (LCA) studies comparing organic farming with other farming systems show favourable results for organic farming when referring to the surface as a functional unit (e.g. Haas et al. 2005; Nemecek et al. 2005; van der Werf et al. 2009). Due to lower yields, the advantages decrease per production amount but still remain obvious in some impact categories. Furthermore, organic farming seems to have advantages in non-classical impact categories such as biodiversity, animal welfare or carbon sequestration (Stolze et al. 2000; Niggli et al. 2009). From a business management point of view as well, organic farms are generally more profitable due to higher product prices and policy support (Sanders et al. 2010). Nevertheless, recent propositions to enhance agricultural policy measures assume that a support for organic farming is not efficient enough, as it does not comply with the *Tinbergen rule* (Mann 2005). This rule says that the number of policy instruments chosen should at least equal the number of targets set (Tinbergen 1952). On the other hand, agriculture is characterised by its multifunctionality, it serves different objects such as nutrient production, food safety, protection of the environment or maintenance of a decentralised settlement pattern and thereby assuring economic life in mountain regions. Due to these links, a specific policy instrument not only affects the target it is aimed at but can have positive or negative effects on all aspects of the agricultural functions. Therefore, an instrument with broad effects may lead to a better overall result than a range of single measures which contain the risk of interfering with non-envisaged purposes. This question is examined by a comparison between the support for organic farming and specific steering measures, evaluating the effects not only on environmental impacts but also on additional aspects of sustainability.

Concerning methodology, increasing efforts are being made to enhance the influence and relevance of LCA for decision-making. The inclusion of cost accounting or Life Cycle Cost (LCC) analysis in LCA has been pursued for quite some time (Norris 2001; Rebitzer and Hunkeler 2003). Despite some methodological differences, e.g. the non-consideration of indirect costs in pure LCC, the combination of these methods results in a better basis for decision-making. Efforts to include social aspects in LCA have increased recently (e.g. Weidema 2006; Dreyer et al. 2010). In addition to methodological differences, the lack of availability of socioeconomic data may be an additional problem (Kruse et al. 2009).

At the same time, efforts to consider environmental impacts in economic decision-support models are increasing (e.g. Andersen et al. 2004; Lehtonen et al. 2005). In many cases, emissions of greenhouse gases are studied by means of climate-economy models (van der Werf and Peterson 2009). Sometimes the life cycle aspect is included, for example by accounting for the primary energy requirements of economic activities (Kränzlein 2009). Most of these decision-support models concern agricultural production. The multifunctionality of this economic sector justifies the public financial support that it receives. The design and evaluation of agricultural regulation therefore needs profound information about the relationship between political measures and their impacts on the different functions of agriculture. Decision-support models could supply this information. However, most decision-support models either examine only individual emissions or indicators or only consider the domestic agricultural production sector. This might lead to preferences of political scenarios in which the environmental impacts are relocated to other environmental categories, to up- or downstream sectors or to foreign countries. Therefore, from an environmental point of view, life cycle thinking is advisable when comparing political scenarios.

The goal of this article is to ascertain if the preference among several political measures can change when applying a combination of an economic decision-support model and the environmental LCA method instead of only one of these instruments. Concretely, the question is if a broad measure such as payments for organic farming is advantageous compared with specific environmental policy measures when considering the different aspects of sustainability simultaneously.

2 Materials and methods

The selected environmental policy measures are evaluated with regard to all dimensions of sustainability. For this purpose, an economic model, which determines the economic behaviour of farmers and estimates economic and socioeconomic indicators, is linked to an LCA tool. The combination of the resulting indicators is analysed with regard to heterogeneous conclusions.

2.1 Economic decision-support model SILAS

Economic models are used to forecast impacts of changes in the business environment on economic activities. They often consist of many restrictions and equations describing technical, institutional and behavioural bounds and interrelations between economic actors, goods and monetary values. Some types of models try to explain the relationships between supply and demand in a whole economy or a sector, while others describe more precisely the supply of a sector or a single enterprise in order to improve allocation of production factors. The models are based on principles such as market equilibrium or utility maximisation.

The sector model Swiss Agricultural Sector Forecasting System (*Sektorales Informationssystem der Landwirtschaft Schweiz* SILAS) has been developed to aid decision-making in Swiss agricultural policy, such as the design of support programmes or the amount of direct payments (Mack and Flury 2006; Mack and Mann 2008). The model has been used for over 10 years to forecast the effects of different policy scenarios on agricultural outputs, sector income and public budget. This forecast is expected to be as realistic as possible over a period of 5 to 10 years. SILAS is a process analysis model of the Swiss agricultural sector, meaning it considers the main interconnections among production factor use and production output (e.g. working hours, fertiliser quantity and grain yield per hectare) and delimits the sector according to the national agricultural accounting statistics. The sector is differentiated by eight regions confronted with specific climatic and topographic conditions. These regions also form the basis for a number of agricultural policy measures. This enables accurate modelling of the Swiss direct payment system, which is characterised by regionally graduated direct payment approaches and contribution restrictions. Furthermore, the relatively homogeneous production potential of individual areas can be realistically represented by the model, as most of the statistical data are available at this regional level.

SILAS is an optimisation model that chooses the quantities of activities, such as crop and animal production, with the objective of maximising or minimising a specific variable and simultaneously complying with production conditions and restrictions which are formulated within thematic modules (Fig. 1). Production modules determine the yields and direct costs of crop and animal activities in Swiss agriculture, considering different climatic regions, levels of intensity and organic and non-organic variants, based on average statistical data. The organic and non-organic activities are based on average statistical data. A fertiliser module ensures the fulfilment of nutrient requirements through manure or commercial fertiliser. A feed ration module calculates lowest cost feed mixtures for all livestock according to animal requirements. A labour module determines the use of hired labour as a function of working-time requirements and available family labour. The model pursues a recursive dynamic approach, which means that building and machinery investments are transferred to the next model year.

Parameters related to the development of technical progress, such as crop yield increases or more efficient machinery, are based on trend extrapolations and expert estimates. Future price developments of products and factors are periodically determined by consulting agricultural administrative experts. This procedure was adopted because pricing of agricultural products is to a great extent affected by market support and tariff policy measures. For

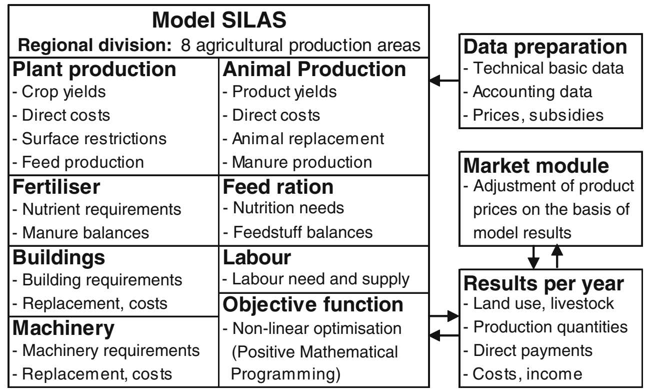

Fig. 1 Structure of the decision-support model SILAS

some important products such as dairy products or cereals, a market module which takes into account EU and world market prices and tariffs has been developed (Ferjani 2008). Accounting equations at regional and sectoral level ensure utilisation of all intermediate agricultural products.

The objective function maximises sector income for 1 year, thus ensuring optimum regional allocation of production. All equations in the model are linear, which means that endogenous variables are not multiplied, ensuring that the algorithm of the solver finds a unique optimum. A disadvantage of purely linear models is an overly inaccurate representation of heterogeneity, as the model chooses the beneficial activities to the largest possible extent. The method of Positive Mathematical Programming (PMP; Howitt 1995) avoids extreme model results by means of additional quadratic parameters in the objective function (replacing linear cost parameters) and ensures that the results for the starting year are calibrated to the amounts of the activities in reality. These non-linear elements in the objective function can be seen as decision-relevant factors such as individual preferences that are not directly considered in the model. They remain constant for the whole forecast period in all scenarios.

The mathematical model can be summarised as follows:

Objective function:

$$\text{Max } Z = \sum_i p_i y_i + \sum_j d_j x_j - \sum_k v_k u_k - \sum_j \alpha_j x_j - \sum_j 0.5\beta_j x_j^2$$

Constraints:

$$R_n : \sum_i a_{ni} y_i + \sum_j b_{nj} x_j + \sum_k c_{nk} u_k \leq r_n$$

$$y_i, x_j, u_k \geq 0$$

Model equations:

Z Objective function (sectoral income)
R Restrictions (technical and institutional production constraints)

Model variables:

y Sales products
x Production activities (arable and livestock)
u Production factors (investments, fertiliser, etc.)

Model parameters:

p Product prices
d Direct payments
v Factor prices
α, β Linear and quadratic PMP-terms
PMP: Positive Mathematical Programming (estimation of additional cost and utility factors that are not directly formulated in the model)

a, b, c Production coefficients (e.g. nutrient needs/ha)
r Capacities (e.g. family workforce available)

Enumerators:

i, j, k Number of products/activities/factors
n Number of constraints

2.2 LCA method and database SALCA

The LCA tool Swiss Agricultural Life Cycle Assessment (SALCA) has been developed by the LCA research group of Agroscope ART. It is used for the analysis of single agricultural products or processes and of real or modelled farms (Nemecek et al. 2008). SALCA consists of a database and a calculation tool. The database contains inventories from the ecoinvent® database (Frischknecht et al. 2004), additional inventories specific to agricultural processes (e.g. differentiation between a larger number of housing systems), emission models describing direct emissions of agricultural production (Table 1)

Table 1 Overview of the models for direct field and farm emissions in SALCA

Emission	Area	Determining factors
Ammonia (NH_3) (Menzi et al. 1997)	Housing	Quantity of N excreted (dependent on animal species, number of animals, animal performance, and feed ration), housing system, and grazing time
	Manure storage	Manure (type and quantity) and storage system (open/closed)
	Manure spreading	Manure, region (climate), season (month), dilution of liquid manure, quantity spread per area, spreading technique, and special measures
	Grazing	Quantity of N excreted and grazing time
	N fertilisation	Type and quantity of chemical N fertiliser
Nitrate (NO_3) (Richner et al. 2006)	Generation in soil	Month, number of animals per surface, type of soil, soil cultivation measures, crop type (uptake of N)
	N fertilisation	Quantity of manure and N fertiliser, month, crop type and soil thickness
	Grazing	Duration of grazing, proportion dung/urine and season
Methane (CH_4) (Minonzio et al. 1998)	Digestion	Quantity of feed uptake (dry matter), percentage of roughage, animal type and animal weight
	Manure storage	Quantity of feed uptake (dry matter), animal type and manure type (percentage of liquid manure)
Nitrous oxide (N_2O) (Schmid et al. 2000)	Manure storage	Manure (type and quantity)
	N fertilisation	Quantity of manure and N fertiliser, N fixation and N harvest residues
	Grazing	Quantity of N excreted, duration of grazing
Nitric oxides (NO_x)		Quantity of N_2O emissions (authors' estimate: linear function of N_2O emissions)
Phosphate (PO_4) (Prasuhn 2006)	Leaching	Crop type, risk category, quantity of manure, P-supply category and drainage
	Run-off	Crop type, risk category, P fertilisation, gradient, type and length of slope, in- and outflow of water and distance to outflow
	Erosion	Erosion (dependent on precipitation, soil type, gradient, length of slope and canopy), P-supply category and distance to outflow
Combustion (Rinaldi et al. 2005)	CO_2, CO, NO_x and hydrocarbons	Use of diesel, tractor power and operating grade
Heavy metals (Freiermuth 2006)		Purchase of fertilisers and feed
Pesticides (Guinée et al. 2002)		Crop type (connected linearly with pesticide requirements per crop type)

and impact models determining classic environmental impacts (Table 2). The different impact methods have been chosen based on their suitability for agricultural processes. In particular, the wide range of pesticides is only partially covered by most methods available. The methods chosen consider some natural products applied in organic farming such as sulphur or fatty acids. The impact assessment follows a midpoint approach. In the case of diversified farms, an approximate allocation of jointly used factors to main product groups such as milk, meat and arable crops is carried out (e.g. forage allocation according to standardised feed requirements and economic allocation in the case of co-products). The aim of this LCA tool, as used in combination with the model SILAS, is to estimate the environmental impacts of modelled farms for different Swiss agricultural policy scenarios. The SILAS model results are therefore scaled down to average farms.

2.3 Linkage between SILAS and SALCA

Both economic models and LCA are based on a specified system of product flows but focus on different effects: economic models include monetary interrelations and human behaviour towards changes, whereas LCA is interested in direct and indirect energy and substance flows and environmental impacts. Based on a system of economic processes, LCA's calculation steps or environmental impacts determined in advance could be integrated into the economic model (Möhring and Zimmermann 2005; Schader 2009). In the case of SILAS, a hierarchical linkage to the LCA tool was chosen (Fig. 2), which means that the SILAS results, mainly the extent of crop an animal activities and the quantities of inputs considered in the model, served as input parameters for the LCA tool. This least close connection ensures that both models can be updated and extended independently.

Nevertheless, all production data necessary for the calculation of the LCA have to be defined, either within SILAS or as an additional data set. Such data not represented in SILAS (e.g. the pesticide products used for a specific crop) were defined using characteristic process parameters for Swiss agriculture available in various statistical data. The national input data are divided according to region (e.g. mountain region) and type of production system (e.g. organic farming) because region and production system are influencing factors in the emission models. In order to avoid large numbers, this subdivided data are scaled down to average farms by applying linear expansion factors targeted on average farm areas. Sales and purchases of feed, manure and animals are balanced between these farms. The LCA results are then scaled up again for further assessment and interpretation.

2.4 Sustainability indicators in the combined model

The evaluation of sustainability is an essential part of the evaluation of Swiss agricultural policy. Several indicators have been developed by the administration covering the range of environmental, economic and socio-political sustainability (BLW 2005). These indicators are estimated periodically by means of statistical data.

The environmental indicators consist of the size of ecological compensation areas, energy use, fertiliser efficiency and pesticide use. The formulation of these topics in the SILAS model is of a different degree of detail. Concerning the ecological compensation areas, the model has the opportunity to choose among various activities such

Table 2 Overview of the environmental impacts considered

Environmental impact		Unit (equivalents)	Determining emissions/resources	Determining inputs/processes
Energy use (Frischknecht et al. 2004)	Non-renewable energy resources, fossil and nuclear	MJ	Crude oil, natural gas and uranium	Fuel, electricity and buildings
Greenhouse effect GWP 100a (IPCC 2001)	Change of the atmosphere by greenhouse gases	kg CO_2	CO_2, CH_4 and N_2O	Direct emissions, fuel, electricity and concentrates
Ozone formation EDIP97 (Hauschild and Wenzel 1998)	Formation of near-surface ozone (high NO_x POCP)	g C_2H_4	Hydrocarbons, CH_4 and CO	Fuel, concentrates and machinery
Eutrophication EDIP97 (Hauschild and Wenzel 1998)	Nutrient entry in soil and water (N+P)	kg N	NH_3, NO_3^-, NO_x and phosphates	Direct emissions and concentrates
Acidification EDIP97 (Hauschild and Wenzel 1998)	Acid entry in soil and water (“acid rain”)	kg SO_2	NH_3, NO_x and SO_x	Direct emissions, concentrates and fuel
Terrestrial ecotoxicity CML01 (Guinée et al. 2002)	Damage of organisms in soil	kg 1,4-DCB	Pesticides, Hg, Cr, Zn and Cu	Pesticides, concentrates and P fertiliser
Aquatic ecotoxicity CML01 (Guinée et al. 2002)	Damage of organisms in waters	kg 1,4-DCB	Pesticides, Cu, Ni, Zn and Cd	Pesticides, concentrates and buildings
Human toxicity CML01 (Guinée et al. 2002)	Human health damage (through air or water)	kg 1,4-DCB	Cr, C_6H_6, As, Ni and pesticides	Buildings, machinery, fuel and concentrates

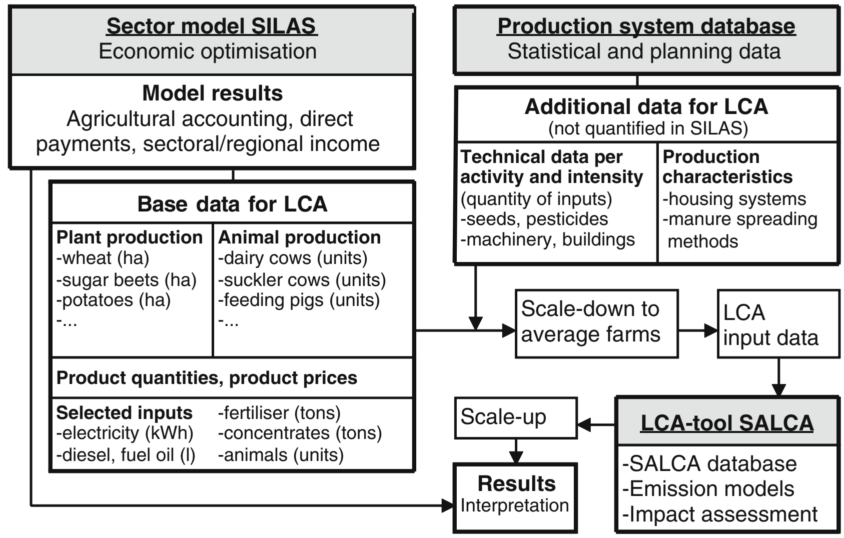

Fig. 2 Link between SILAS and the LCA tool SALCA

as extensively used grassland or hedgerows. These activities are supported financially or account for fulfilling cross compliance. The consumption of fossil energy carriers is bound to the use of machinery and buildings. In order to consider energy-saving measures induced by rising energy prices, factors for elasticity of demand are formulated, which have been derived from past accountancy data and price developments. According to this analysis, a diesel price increase of 10% leads to a decrease in diesel demand of 1.6%. Due to lack of price fluctuations during the past several years, this elasticity is assumed to be valid for electricity too. In the case of fuel, the decrease in demand observed is 4.2%. This reduction is supposed to be achieved through technical progress and organisational measures without costs. Concerning fertiliser efficiency, different application levels are formulated in the model, as well as a substitution of fertilisers with manure. In contrast, pesticide use per crop is fixed; a change in the recommended amount is not formulated. Therefore, a specific political measure to reduce pesticide use is not defined in this analysis. Instead, concentrate use is considered, which can be modified in the model within the limits of the nutrient needs of the animals. The environmental impacts of animal husbandry are strongly connected to the production of concentrates which could be replaced partly by roughage and by-products such as whey.

An important socioeconomic sustainability indicator is agricultural income (net income), which is also a main variable in the SILAS model. Some other indicators defined by the national administration cannot be formulated adequately within the model (professional qualification, quality of life) or they depend strongly on model assumptions (age of equipment, depending on the economic life of buildings and machinery predefined; labour productivity, depending on estimated technical progress). Therefore, additional indicators connected to agricultural policy goals are considered, especially the size of the workforce in mountain regions and the degree of calorific self-sufficiency.

2.5 System boundaries and functional units

Since the focus of the model lies on agricultural production, the processing, distribution and consumption of agricultural products (downstream sectors) are not taken into account. Hence, the system boundary is at the farm gate. In the case of socioeconomic indicators (e.g. income), possible relation to the provision of production factors (upstream sectors) is not considered either. The environmental results are related to different functional units according to the multifunctionality of agriculture: agricultural area, food energy produced, protein produced and income. In the case of socioeconomic indicators, some values already represent ratios, such as the percentage of self-sufficiency; for others (e.g. employment in the mountain region), the most meaningful reference is the agricultural sector as a whole, equivalent to the whole area.

3 Support for organic farming compared to specific environmental measures

3.1 Definition of scenarios

The model combination was applied to different policy scenarios with predefined economic conditions in a time period from 2008 to 2015 (Table 3). The reference scenario contained the developments in product and factor prices predicted by the Swiss agricultural administration, which assumed a further decrease in product prices, but an increase in various factor prices, notably for energy.

Table 3 Prices and direct payments of the scenarios for the year 2015

Scenario	Ref	Org	Eco	Ene	Fer	Con	Comb
The relative changes refer to	Ref 2008	Ref 2015	Ref 2015	Ref 2015	Ref 2015	Ref 2015	Ref 2015
Average product price development	−7%	–	–	–	–	–	–
Average factor price development	+3%	–	–	+1.2%	+0.6%	+3.0%	+1.2%
Average direct payments development	+11%	+0.4%	+0.2%	+3.3%	+4.1%	+3.5%	+3.2%
Reduction of energy needs induced by price increases							
Electricity	−3%	–	–	−3.7%	–	–	−0.9%
Diesel+fuel	−5%	–	–	−5.8%	–	–	−1.5%
Direct payment for organic farming	–	+253%	–	–	–	–	–
Direct payment for ecological compensation areas	–	–	+51%	–	–	–	+13%
Price of energy carriers	+17%	–	–	+15%	–	–	+4%
Price of mineral fertilisers	+14%	–	–	+8%	+73%	–	+20%
Price of concentrates	−8%	–	–	–	–	+10%	+2%
Payments (+) and taxes (−) caused by the scenario measures		+97	+99				+20
(model results; 10^6 CHF)				−97	−108	−101	−89
Compensation: farm subsidy		−97	−99	+97	+108	+101	+69

Ref reference scenario, *Org* organic farming support, *Eco* ecological compensation area support, *Ene* fossil energy tax, *Fer* mineral fertiliser tax, *Con* concentrates tax, *Comb* combination Eco+Ene+Fer+Con (reduction of the modification rates to 25%)

Reductions of market support were partly compensated by increasing direct payments. The reference scenario was the basis for all additional scenarios, in which the conditions were only slightly modified by increasing the value of one single parameter, according to the chosen policy measures. Organic farming was supported via an increase in direct payments per hectare. This measure was compared to a support for ecological compensation areas and taxes on fossil energy, mineral fertiliser or concentrates, respectively, as well as a combination of these four measures. To remain comparable, the modification rates in the additional scenarios were set to achieve the same impact on the public budget, which was assumed to be approximately 100 million CHF. This amount directly resulting from the modifications was compensated through general direct payments. Nevertheless, the sum of direct payments varied due to model reactions. For sensitivity analysis reasons, the modification rates were doubled in a second run and the resulting impact on the public budget (varying around 200 million CHF) was compensated again. In the case of organic farming support, the contribution per hectare increased five times this way, but since the absolute value was relatively small in the reference year, this increase did not exceed the amount of the general direct payments per hectare.

4 Results

A selection of the results calculated by means of the economic model is shown in Table 4. The reference scenario for 2015 is compared with the data for 2008, and the additional scenarios display changes relative to the reference scenario results. In most cases, the doubling of the modification rates leads to further changes in the same direction in which they occurred with single modification rates, but these further changes are smaller due to increasing adaptation expenditures. Concerning the scenario differences, the effects of the altered modification rates are low. Therefore, and since the scenario differences are generally small, only the results with doubled modification rates are shown.

Decreasing product prices in the reference scenario lead to a reduction of both arable and livestock farming. In contrast, ecological compensation areas increase. Due to productivity progress, production of food energy remains constant; therefore, the proportion of fat slightly decreases due to a decline in oilseed cultivation. The decrease in the price of concentrates leads to higher imports. Most other inputs become more expensive which, despite raising direct payments, results in a considerable income loss in the sector.

Further effects of most of the additional scenarios are relatively small because only one single parameter is changed in each case. A rise in the financial support for

Table 4 Economic model results of the scenarios for the year 2015 (values for non-reference scenarios indicate differences relative to reference in 2015)

Scenario		Ref		Org	Eco	Ene	Fer	Con	Comb
		Absolute values	Changes	Level 2	Level 2	Level 2	Level 2	Level 2	Level 2
The relative changes refer to			Ref 2008	Ref 2015	Ref 2015	Ref 2015	Ref 2015	Ref 2015	Ref 2015
Open arable area	1,000 ha	243	−3.6%	−0.1%	−4.6%	+0.4%	−4.7%	+2.2%	−1.7%
Livestock	1,000 LU	1,210	−5.7%	−0.2%	−2.8%	−0.4%	+1.9%	−3.2%	−2.0%
Organic area	1,000 ha	108	−5.0%	+87.2%	−1.4%	−0.6%	−10.9%	+1.5%	−3.9%
Organic livestock	1,000 LU	109	−5.8%	+78.0%	−1.2%	−0.5%	−6.6%	+1.3%	−3.5%
Ecological compensation area	1,000 ha	126	+23.2%	−0.7%	+70.3%	+1.3%	+4.6%	+1.2%	+21.8%
Stocking rate	LU/ha	1.33	−2.5%	+0.1%	+2.8%	−0.3%	+2.5%	−3.1%	−0.0%
Energy purchase: diesel	kg/ha	111	−7.6%	−0.4%	−2.1%	−7.8%	−0.6%	−1.1%	−3.1%
Energy purchase: electricity	MJ/ha	2,738	−3.7%	−5.7%	−6.0%	−11.4%	−2.2%	−7.8%	−7.7%
Fertiliser purchase: nitrogen	kg N/ha	32	−10.1%	−4.8%	−6.2%	−0.5%	−10.6%	+5.4%	−1.3%
Manure: disposable N	kg N/ha	48	−3.1%	−0.5%	−2.8%	−0.6%	+1.7%	−3.5%	−2.1%
Concentrate purchase	1,000 t	1,018	+11.7%	−6.0%	+0.5%	−0.3%	+11.4%	−14.9%	−4.1%
Concentrates fed per cow	kg/cow	977	+33.2%	−1.5%	+0.1%	+0.2%	+1.1%	−2.0%	−0.3%
Production of food energy	TJ	25,398	+0.2%	−1.6%	−3.6%	−0.4%	−2.1%	−2.0%	−2.3%
Production of carbohydrates	1,000 t	644	+1.4%	−1.1%	−4.2%	−0.2%	−6.6%	+1.0%	−2.1%
Production of protein	1,000 t	231	+1.1%	−1.3%	−3.2%	−0.3%	−0.3%	−3.3%	−2.4%
Production of fat	1,000 t	278	−1.2%	−2.1%	−3.3%	−0.6%	+1.2%	−4.4%	−2.6%
Production value	10^6 CHF	7,645	−7.0%	−0.0%	−2.5%	−0.4%	+0.5%	−5.3%	−4.3%
Direct payments	10^6 CHF	2,865	+11.0%	+0.7%	+0.5%	+6.8%	+7.7%	+7.2%	+6.2%
Total external costs	10^6 CHF	8,182	+1.2%	−0.2%	−2.0%	+1.1%	+3.0%	−2.1%	−2.0%
Energy costs	10^6 CHF	407	+6.4%	−0.9%	−2.1%	+19.9%	+0.6%	−2.1%	+4.2%
Fertiliser costs	10^6 CHF	139	+2.6%	−5.5%	−6.4%	+16.9%	+113.2%	+8.0%	+42.4%
Concentrates costs	10^6 CHF	1,451	+10.9%	−0.7%	−1.7%	−0.3%	+4.1%	−7.2%	−11.5%
Income	10^6 CHF	2,328	−14.3%	+1.4%	−0.5%	+3.4%	+0.8%	−1.5%	+0.6%

Ref reference scenario, *Org* organic farming support, *Eco* ecological compensation area support, *Ene* fossil energy tax, *Fer* mineral fertiliser tax, *Con* concentrates tax, *Comb* combination Eco+Ene+Fer+Con (reduction of the modification rates to 25%), *Level 2* doubled modification rates, *LU* livestock units

organic farming, however, leads to a considerable extension of organically managed land and livestock. The higher payments for ecological compensation areas results in a further extension of these areas, resulting, as a consequence, in lower food production. The energy tax leads to the assumed energy savings, but not to important shifts between production activities, because the main agricultural activities all need energy to a similar extent. In contrast, a tax on fertiliser provokes a shift from plant to animal production activities, a tax on concentrates reduces livestock, especially pig and poultry husbandry. The higher direct payments in the scenarios involving taxes are caused by compensation of the higher factor costs.

Regarding socioeconomic indicators covering income, workforce and nutrition-safety topics (Table 5), higher direct payments for organic farming (approximately compensated by reduced general direct payments) increase sector income related to the lowered income in 2015. This income amelioration especially occurs in the mountain region where a shift to organic farming often only needs few adaptations. The energy tax (compensated by higher general direct payments) leads to an even higher income which can be explained by the assumed possibilities of energy savings. In contrast, a tax on concentrates decreases the income mainly in the valley regions where the majority of pig and poultry husbandry is located. This animal husbandry generates higher incomes per area compared to the increasing crop production activities, which, in addition, often need to hire specialised harvest technology. The preservation of jobs is highest in the organic scenario, and all scenarios result in lower nutrition self-sufficiency. The combined scenario tends to be less favourable to the socioeconomic indicators than the organic scenario.

Table 5 Socioeconomic indicators of the scenarios for the year 2015 (values for non-reference scenarios indicate differences relative to reference in 2015)

Scenario		Ref		Org	Eco	Ene	Fer	Con	Comb
		Absolute values	Changes	Level 2	Level 2	Level 2	Level 2	Level 2	Level 2
The relative changes refer to			Ref 2008	Ref 2015	Ref 2015	Ref 2015	Ref 2015	Ref 2015	Ref 2015
Total Income	10^6 CHF	2,328	−14.3%	+1.4%	−0.5%	**+3.4%**	+0.8%	−1.5%	+0.6%
Income valley region	10^6 CHF	1,162	−16.3%	−3.1%	**+2.1%**	**+3.6%**	+0.3%	−4.2%	+0.9%
Income hill region	10^6 CHF	545	−9.3%	+0.9%	−0.2%	**+2.4%**	+0.4%	−2.6%	+0.1%
Income mountain region	10^6 CHF	620	−14.7%	**+10.5%**	−5.4%	**+3.8%**	**+2.0%**	**+4.5%**	+0.2%
Income per family workforce	CHF/year	36,082	−3.3%	+1.5%	+0.7%	**+3.8%**	**+2.2%**	+0.0%	**+2.3%**
Total Workforce	Units	88,267	−12.3%	+0.6%	−1.6%	−0.2%	+0.2%	−0.9%	−0.9%
Salaried workforce	Units	23,747	−14.9%	**+2.4%**	−3.0%	+0.4%	**+4.5%**	+0.7%	+1.5%
Workforce in mountain region	Units	19,198	−10.2%	+1.2%	−1.9%	−0.0%	−0.9%	−0.2%	−1.1%
Alpine pasture usage	1,000 LU	191	−17.4%	**+2.2%**	−1.9%	−1.2%	+1.5%	−0.6%	−2.1%
Gross calorific self-sufficiency	%	60%	+0.1%	−1.0%	−2.2%	−0.2%	−1.3%	−1.2%	−1.4%
Net calorific self-sufficiency	%	56%	−0.4%	−1.8%	−3.3%	−1.2%	−2.9%	−1.2%	−2.1%
Gross protein self-sufficiency	%	74%	+0.8%	−1.0%	−2.4%	−0.2%	−0.3%	−2.5%	−1.8%
Net protein self-sufficiency	%	62%	−0.6%	−2.6%	−4.4%	−2.1%	−3.4%	−2.3%	−3.0%

Entries in bold: Increase of more than 2.0% compared to the reference scenario (arbitrary threshold for reasons of visualisation)

Ref reference scenario, *Org* organic farming support, *Eco* ecological compensation area support, *Ene* fossil energy tax, *Fer* mineral fertiliser tax, *Con* concentrates tax, *Comb* combination Eco+Ene+Fer+Con (reduction of the modification rates to 25%), *Level 2* doubled modification rates, *LU* livestock units

The ecological impacts of the different scenarios are shown in Table 6, related to the different functional units. Contrary to the socioeconomic indicators, a decrease in the environmental effects is favourable. In the reference scenario, remarkable reductions of the impacts appear during the considered time period per ha, GJ food energy and t protein. This is mainly caused by technical progress which was assumed to continue as it had in past years, i.e. higher yields achieved by plant and livestock breeding or less demand for energy, capital and work due to improved production processes. In addition, the assumed development of the economic conditions leads to a reduction of greenhouse production and consequently to a further decrease in national energy demand.

Compared with this reference scenario, the energy and concentrates tax scenarios are favourable for most impacts and functional units. This is mainly caused by the assumed general energy savings and the shift from animal to plant production activities, respectively. The organic scenario shows smaller changes but is still favourable when related to area or income. The slightly increased acidification potential per ha in this scenario is caused by higher ammonia emissions from manure spreading, which is assumed to be spread over an expanded surface, while conventional farming tends to use mineral fertiliser on arable land. On the other hand, nitrate emissions, which cause about half of the eutrophication potential, decrease due to the lower fertilisation and feeding intensity in organic farming. The support for ecological compensation areas causes higher impacts in relation to the lower food production. A tax on mineral fertiliser leads to the highest increases in impacts due to the shift to animal production activities. The impacts of the combined scenario are partly smaller than the ones of the organic scenario, especially per area and food energy, but altogether the difference is low.

Overall, the predicted developments in product and factor prices combined with assumed reductions of public payments, as represented by the 2015 reference scenario, have the greatest effect on the environmental impacts, with a reduced environmental burden per hectare, per GJ food energy and per t protein. However, effects on income and workforces are negative and hence also for the environmental impacts per 1,000 CHF income. The effects on the additional scenarios were less clear. Figure 3 represents the changes in some important indicators. Concerning the socioeconomic indicators, the organic scenario tends to be favourable compared with the combined scenario, but the differences are small. Additional indicators not considered in this study seem to argue for organic farming: biodiversity and soil fertility often increase on organically managed farms compared to conventional farms (Nemecek et al. 2005). Furthermore, the demand for organic products in Switzerland is growing, which implies a lower pressure of an increasing supply on prices. The ecological-compensation-area scenario also reduces most environmental impacts, but at the same time it results in a decrease in production. Comparing the four specific policy measures, a tax on energy or concentrates is environmentally more favourable than a tax on fertiliser or a support for

Table 6 Ecological results of the scenarios for the year 2015 (values for non-reference scenarios indicate differences relative to reference in 2015)

Scenario		Ref		Org	Eco	Ene	Fer	Con	Comb
		Absolute values	Changes	Level 2	Level 2	Level 2	Level 2	Level 2	Level 2
The relative changes refer to			Ref 2008	Ref 2015	Ref 2015	Ref 2015	Ref 2015	Ref 2015	Ref 2015
Per ha									
Energy use	GJ	51.2	−8.8%	−1.4%	−0.7%	**−3.9%**	+2.7%	**−3.9%**	−2.9%
Greenhouse effect	kg CO_2	8,275	−3.0%	−0.9%	−1.9%	−1.7%	+2.0%	**−2.7%**	−1.9%
Ozone formation	g C_2H_4	3,840	−3.3%	−0.5%	−0.1%	**−2.8%**	+5.3%	**−4.4%**	−1.8%
Eutrophication	kg N	123	−2.9%	−0.8%	**−3.0%**	−0.6%	+2.8%	**−3.9%**	**−2.1%**
Acidification	kg SO_2	123	−2.9%	+0.1%	**−2.8%**	−1.1%	+3.2%	**−4.6%**	**−2.8%**
Terrestrial ecotoxicity	kg 1,4-DCB	8.36	−2.7%	**−2.0%**	−0.0%	−0.5%	+4.0%	**−4.0%**	−1.2%
Aquatic ecotoxicity	kg 1,4-DCB	194	+0.5%	**−2.5%**	+0.7%	−0.3%	+6.9%	**−6.5%**	−1.4%
Human ecotoxicity	kg 1,4-DCB	1,380	−2.6%	−1.2%	−1.3%	**−2.3%**	+3.0%	**−3.5%**	**−2.3%**
Per GJ food energy									
Energy use	GJ	2.10	−9.2%	+0.4%	+2.9%	**−3.4%**	+5.2%	−1.8%	−0.5%
Greenhouse effect	kg CO_2	339	−3.4%	+0.9%	+1.7%	−1.2%	+4.4%	−0.7%	+0.5%
Ozone formation	g C_2H_4	157	−3.8%	+1.4%	+3.5%	**−2.3%**	+7.8%	**−2.4%**	+0.7%
Eutrophication	kg N	5.02	−3.4%	+1.0%	+0.5%	−0.1%	+5.3%	−1.8%	+0.3%
Acidification	kg SO_2	5.04	−3.3%	+2.0%	+0.8%	−0.6%	+5.7%	**−2.6%**	−0.4%
Terrestrial ecotoxicity	kg 1,4-DCB	0.34	−3.2%	−0.2%	+3.6%	+0.0%	+6.5%	−1.9%	+1.2%
Aquatic ecotoxicity	kg 1,4-DCB	7.94	+0.1%	−0.7%	+4.4%	+0.2%	+9.4%	**−4.6%**	+1.0%
Human ecotoxicity	kg 1,4-DCB	56.5	−3.1%	+0.6%	+2.3%	−1.8%	+5.4%	−1.5%	+0.1%
Per t protein									
Energy use	GJ	230.5	−10.0%	+0.1%	+2.5%	**−3.5%**	+3.3%	−0.4%	−0.4%
Greenhouse effect	kg CO_2	37,225	−4.4%	+0.6%	+1.3%	−1.3%	+2.5%	+0.8%	+0.6%
Ozone formation	g C_2H_4	17,277	−4.7%	+1.0%	+3.1%	**−2.4%**	+5.9%	−1.0%	+0.8%
Eutrophication	kg N	552.3	−4.3%	+0.7%	+0.1%	−0.1%	+3.4%	−0.4%	+0.4%
Acidification	kg SO_2	553.9	−4.3%	+1.7%	+0.3%	−0.7%	+3.8%	−1.2%	−0.3%
Terrestrial ecotoxicity	kg 1,4-DCB	37.61	−4.1%	−0.5%	+3.2%	−0.0%	+4.6%	−0.5%	+1.3%
Aquatic ecotoxicity	kg 1,4-DCB	872.8	−0.9%	−1.0%	+3.9%	+0.2%	+7.5%	**−3.2%**	+1.1%
Human ecotoxicity	kg 1,4-DCB	6,208	−4.0%	+0.3%	+1.8%	−1.9%	+3.5%	−0.1%	+0.2%
Per 1,000 CHF income									
Energy use	GJ	22.9	+6.1%	**−2.7%**	−0.4%	**−6.9%**	+2.2%	**−2.3%**	**−3.4%**
Greenhouse effect	kg CO_2	3,694	+12.8%	**−2.2%**	−1.6%	**−4.8%**	+1.4%	−1.1%	**−2.4%**
Ozone formation	g C_2H_4	1,714	+12.5%	−1.7%	+0.3%	**−5.9%**	+4.7%	**−2.8%**	**−2.2%**
Eutrophication	kg N	54.8	+13.0%	**−2.0%**	**−2.7%**	**−3.7%**	+2.2%	**−2.3%**	**−2.5%**
Acidification	kg SO_2	55.0	+13.0%	−1.1%	**−2.4%**	**−4.2%**	+2.6%	**−3.0%**	**−3.3%**
Terrestrial ecotoxicity	kg 1,4-DCB	3.73	+13.2%	**−3.3%**	+0.3%	**−3.6%**	+3.4%	**−2.4%**	−1.7%
Aquatic ecotoxicity	kg 1,4-DCB	86.6	+16.9%	**−3.7%**	+1.0%	**−3.4%**	+6.3%	**−5.0%**	−1.9%
Human ecotoxicity	kg 1,4-DCB	616	+13.3%	**−2.4%**	−1.0%	**−5.3%**	+2.4%	−1.9%	**−2.8%**

Entries in bold: Decrease of more than −2.0% compared to the reference scenario (arbitrary threshold for reasons of visualisation)

Ref reference scenario, *Org* organic farming support, *Eco* ecological compensation area support, *Ene* fossil energy tax, *Fer* mineral fertiliser tax, *Con* concentrates tax, *Comb* combination Eco+Ene+Fer+Con (reduction of the modification rates to 25%), *Level 2* doubled modification rates, *LU* livestock units

ecological compensation areas. The energy tax does not only affect agriculture but would also have extensive effects on the whole economy. The fertiliser scenario shifts production to animal husbandry and therefore shows comparatively the most unfavourable impacts on the environment, even for the impact of eutrophication which is supposed to be particularly targeted at with this measure. The tax on concentrates would be an effective measure to decrease the environmental impacts, because most impacts are affected by concentrate use. However, agricultural income would be reduced and environ-

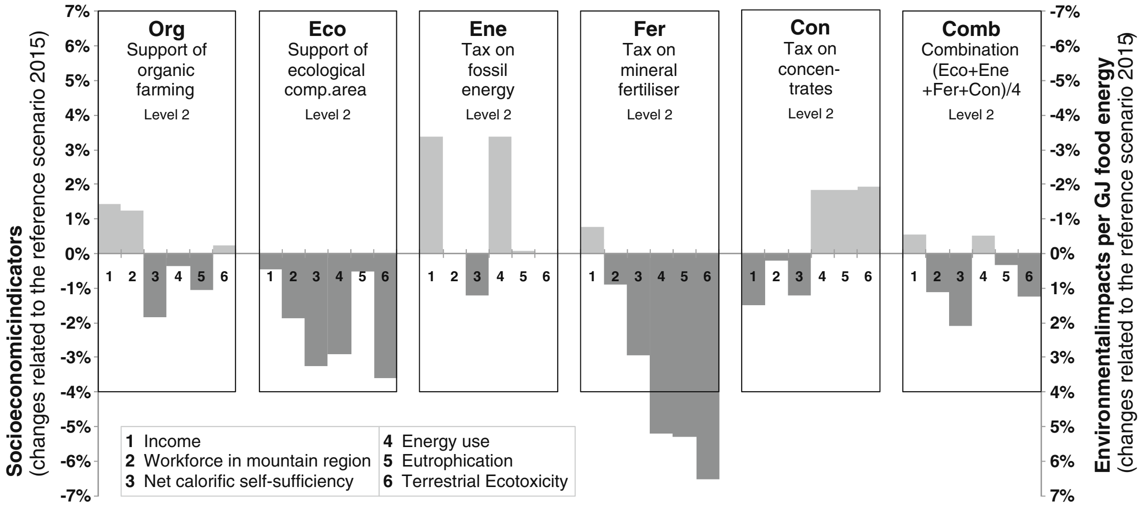

Fig. 3 Overview of socioeconomic and environmental indicators of the scenarios for the year 2015

mental benefits of lower livestock production may be eliminated by higher imports.

5 Discussion

LCA studies comparing organic farming with conventional farming show mostly favourable results for the organic system, especially per area as functional unit (e.g. Nemecek et al. 2005 and sources cited therein). But the differences between the studies are considerable, due to varying process parameters and LCA methods. Furthermore, findings are different depending on the agricultural product, and farm management plays an important role. The present study does not compare conventional with organic farming by assuming a change in production system over the entire agricultural area, which would not be realistic. Instead, it evaluates the effects of increased direct payments for organically farmed land. Since the organic proportion of the agricultural area only increased from 10% to 19% in the organic-farming support scenario, environmental impacts of all farming activities changed little.

One goal of this paper was to verify if a support of organic farming is advantageous compared with more specific environmental policy measures when considering socioeconomic and environmental indicators together. Since the results for the organic scenario did not clearly outperform all other single measures studied, this could not be confirmed. However, the holistic approach of organic farming seems to reduce the risk of undesired side effects on socioeconomic and environmental indicators. In contrast, the study revealed a change in preferences among the other environmental policy measures when extending LCA with an economic model. For example, the support for ecological compensation areas was unfavourable in regard to the socioeconomic indicators considered, and the fertiliser tax led to an increase in environmental impacts instead of the decrease expected.

By combining the method of LCA with decision-support models, an increase in the application spectrum and the quality of conclusions compared with the use of the single instruments alone can be achieved, due to the simultaneous availability of indicators covering different sustainability domains. The results of the economic optimisation model are transferred to the LCA tool via a data interface. Compared to integration in one large model, this type of connection ensures the maintenance of the degree of detail of the single models. It also reduces system complexity and facilitates model updating and improvement.

6 Conclusions

A support for organic farming would be a measure with broad effects, ameliorating several environmental and socioeconomic indicators. The holistic viewpoint of organic farming decreases the risk of unexpected effects. Organic farming tends to be favourable concerning additional impacts specific to agriculture such as biodiversity and soil quality. Methods to assess these impacts have been developed but are not yet included in the LCA tool utilised. However, certain specific policy measures could reach parts of the targets more efficiently: an energy tax would stimulate the application of available energy saving measures but perhaps affect the competitiveness of the whole economy, while a tax on concentrates would lessen the environmental burden but negatively influencing some socioeconomic indicators. The other specific measures examined, in particular a support for ecological compensation areas and a tax on fertilisers, neither clearly reduce the environmental impacts nor improve the

socioeconomic situation of Swiss agriculture; instead, they increase environmental impacts related to food production. Consequently, these measures can be discarded.

Theoretically, specific measures are more efficient than multiobjective ones, but unexpected effects such as the shift to animal husbandry in the case of the fertiliser tax may appear. Therefore, the combination of decision-support models with LCA improves the basis of decision-making, as different aspects can be balanced in the decision process. This combination offers the possibility of using LCA more often in political consulting and decision-making. This is of particular interest in the case of agriculture, where environmental aspects are part of the goals of agricultural policy. The combination of the decision-support model SILAS with the LCA tool SALCA is feasible and functional. The chosen approach proved to be flexible, simplifying updates and extensions of the model. The model SILAS presents a basis for further indicators, especially socioeconomic indicators such as labour costs, working hours or age distribution, that could result in a social-welfare impact category (Kruse et al. 2009). To consider even more social indicators on a single-farm basis, an application of this kind of combination with a multi-agent decision-support model, as is currently being developed at Agroscope ART (Möhring et al. 2009), could be of interest.

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